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LLNL X-band Test Station Commissioning and X-ray Status

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LLNL X-BAND TEST STATION COMMISSIONING AND X-RAY STATUS*

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Abstract

An X-band test station is being commissioned at LLNL to support inverse Compton-scattering x-ray and gamma-ray source development. The X-band test station has been built and this presentation will focus on its current status and the generation of first electron beam. Special focus will be placed on the high gradient conditioning of the T53 traveling wave accelerator and Mark 1 X-band standing wave RF gun. Design and installation of the inverse-Compton scattering interaction region, future upgrade paths and configuration for a variety of x-ray and gamma-ray applications will be discussed along with the status of theory and modeling efforts.

INTRODUCTION

Extremely bright narrow bandwidth gamma-ray sources are expanding the application of accelerator technology and light sources in new directions. LLNL has a successful history utilizing gamma-rays generated by a linac-driven, laser-based Compton scattering gamma-ray source [1, 2, 3, 4]. Next generation advancements in linac-based x-ray and gamma-ray production require increasing the average flux of gamma-rays at a specific energy (that is, $N/eV/sec$ at the energy of interest). One way to accomplish this is to increase the effective repetition rate by operating the RF photoinjector in a multi-bunch mode, accelerating multiple electron bunches per RF pulse. This multi-bunch mode will have stringent requirements for the electron bunch properties including low emittance and energy spread, but across multiple bunches. An X-band test station is under construction at LLNL to develop multi-bunch electron beams and generate x-rays. This paper summarizes progress and describes the current status of the project.

The RF gun is described in detail in [5]. Test station parameters are summarized in Table 1. Beam dynamics are summarized in Fig. 1 for a 250 pC bunch generated in the Mark 1 X-band RF gun and accelerated by a single T53 traveling wave accelerating section. Beam steering will use X-Y windowpane dipole magnets, and two quadrupole triplets will focus the beam for transport and quad-scan emittance measurement. A dump dipole magnet will double as a spectrometer once it has been calibrated.

Table 1: Test Station Parameters

Charge	25–250 pC
Bunch Duration	2 ps
Bunch Rise/Fall	<250 fs
Normalized Emittance	<1 mm mrad
Gun Energy	7 MeV
Cathode Field	200 MV/m
Coupling β	1.7
Section Gradient	~70 MV/m
Final Energy	30 MeV

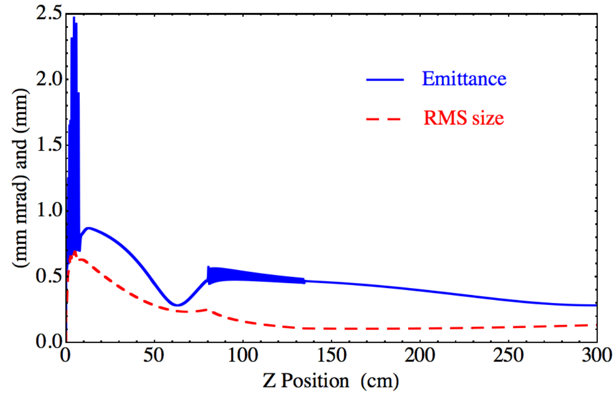

Figure 1: PARMELA beam dynamics simulation for a bunch charge of 250 pC.

TEST STATION

The test station layout is shown in Fig. 2. The high voltage modulator and X-band tube reside in a separate area with RF distribution fed through a hole in the wall to the linear accelerator. A manifold divides the power between the RF gun and the accelerating sections. Testing of the klystron to full power is complete. Support structures made from 80/20 mount to the laser tables and provide multi-dimensional adjustment for alignment of supported components to the beamline. The emittance compensation solenoid for the RF gun is mounted on precision ground rails so that it can be moved back to provide access to the gun. The gun support structure holds the RF gun, WR-90 pumpouts and pumps, as well as an RF gate valve on the beamline. The T53 accelerating structure is mounted on a SLAC designed strongback with end-to-end adjustment, which is then mounted on 80/20 supports that provide additional adjustment as well as support for RF distribution, loads, and vacuum pumps. The quadrupole magnets are

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Figure 2: Photograph of the X-band test station.

mounted together in triplets, with each stand having adjustability. The steering magnets are mounted onto beamline vacuum flanges.

Alignment

The alignment specification on most components, driven by the desire to limit emittance growth, is $\pm 100\ \mu$m. An initial alignment procedure was developed for a 250 MeV X-band linac at LLNL [6], which has been adapted to the X-band test station. The general approach for alignment uses a precision CMM arm from Romer, with a quoted specification of $\pm 75\ \mu$m repeatability and volumetric accuracy over the full envelope reachable by the arm. The coordinate system of the arm is based on geometric features of individual components such as the cross-section of magnet pole pieces, or the outer radii of pillbox cell cups, combined with tooling ball fiducials that have been placed on magnets and accelerating structures. Initial measurement of the geometric features allows the external fiducials to be used in the future when features may be less accessible. A more complete description of this process is reported in [7]

Bakeout

The RF gun vacuum system is comprised of: an RF input window; a WR-90 pumpout; the Mark 1 RF gun; a custom weldment cross; an all-metal RF gate valve; a hot cathode vacuum gauge; two 10 L/s ion pumps; two 40 L/s ion pumps; and additional vacuum nipples, T's, blanks, and an all-metal angle valve to connect the major components. After final assembly and alignment of this unit, the entirety of the system excluding the pump magnet housings has been wrapped with heater tape and aluminum foil, and baked to 120°C for over a week. A base pressure of $1\ 10^{-9}$ Torr has been achieved.

Baking the completed vacuum system of the beamline and RF distribution will provide the best possible starting point for RF processing and commissioning. The T53 accelerator section, gun diagnostic pop-in and photocathode laser mirror box, as well as the full RF distribution up to the klystron output window form a single vacuum system. The complete system bake was planned using 13 independent heater tape and PID control channels. The system was baked to 100°C for over a week and base pressures of 1–2 10^{-9} Torr have been achieved at room temperature.

Conditioning

RF processing of the T53 accelerator section and Mark 1 photo gun is nearly complete. The control system for critical accelerator diagnostics is in place and has been tied into the arc detection system that was used for RF commissioning of the XL-4 klystron. The arc detection chassis is active on the klystron forward and reverse, the RF gun forward and reverse, and the accelerator section forward and reverse. In addition the same NI chassis that does the real time monitoring acts as a digitizer for the modulator voltage and current, as well as other beam diagnostic signals. In order to condition most safely, the accelerator section was brought to full power first, so that the transport waveguide can be processed and the control system can be debugged.

The Mark 1 photo gun is a unique high gradient structure because it is both multi-cell and standing wave. Understanding fundamental limits to high gradient structures benefits from consistent data on varied structure design, and information from this gun will be useful in determining gradient limits, along the lines of [8]. Qualitative observations on processing this structure have been vital in the conditioning process and understanding the best path forward to photo beam generation. The gun is currently processed to 175 MV/m and first beam has been generated and accelerated by the traveling wave section. Both achievements show the system to be well aligned and ready for tuning in order to optimize x-rays.

Laser

There are two laser systems involved in the x-ray generation system at LLNL. The first is the Photocathode Drive Laser, which generates the electron beam. It is a chirped pulse amplification system, based on Ti:Sapphire that is shared with the main S-band 100 MeV accelerator facility. This laser provides up to 20 mJ of uncompressed IR light which is transported to the accelerator, where a dedicated compressor and frequency tripler compresses the pulse to 150 fs. Typically, 15 μJ of UV light is used to illuminate the cathode, but up to 150 μJ is currently available.

The second laser is a commercial frequency doubled Nd:YAG laser that produces up to 800 mJ of 532 nm light in a 6 ns pulse. The ideal laser would be a few-ps long laser pulse, which would increase the total x-ray flux by a couple orders of magnitude. We have demonstrated such a system in the past, but havent integrated it into the X-band test station. For the current work underway, the commercial system in place is sufficient.

Interaction Region

The final accelerated beam will be diverted from and returned to the main beam axis by a magnetic chicane. This allows us to both shield the downstream x-ray diagnostic from on-axis dark current bremsstrahlung noise in the high-gradient components as well as collect the laser light after the scattering interaction. The beam will then be focused to a $<$20 μm spot by a quadrupole triplet, at which point it will interact with the laser. After the interaction, the beam is diverted from the x-ray path with a dipole that doubles as a spectrometer and the beam is then dumped in a carbon block. The laser beam will be focused to a 50 μm rms spot with a 1 m focal length lens, passing though the spectrometer dipole as well as one of the chicane dipoles before being collected and dumped.

CONCLUSION

The major components for the X-band test station have been designed, fabricated, installed, aligned, and are being commissioned for final operation. The XL-4 klystron has been delivered, dressed and installed in the ScandiNova modulator, and tested to full peak power [9]. Assembly of RF transport, test station supports, and accelerator components, final assembly and bakeout have been completed. RF conditioning of the vacuum RF transport, accelerator section, and RF gun is nearing completion. Laser transport for the photocathode drive laser and the laser system safety interlock system installation are complete.

Conditioning is focusing on processing the RF gun to full operating power, which corresponds to 200 MV/m peak electric field on the cathode surface. Reaching the full gradient will generate the highest brightness electron beam possible. Breakdown data for this unique standing wave accelerator structure will also be of great interest to establishing generalized gradient limit figures of merit. Single bunch commissioning of the Mark 1 design is providing confidence that this first structure operates as designed, and will serve as a solid starting point for subsequent changes, such as a removable photocathode, and the use of various cathode materials for enhanced quantum efficiency. Charge scaling experiments will follow, partly to confirm predictions, as well as to identify important causes of emittance growth, and their scaling with charge. Multi-bunch operation will conclude testing of the Mark 1 RF gun, and allow verification of code predictions, direct measurement of bunch-to-bunch effects, and initial implementation compensation mechanisms. Full installation of the interaction region is underway with x-ray interaction planned for this summer. Generation of x-rays with the complete test station system will enable future x-ray source development and applications at LLNL

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